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Medical Data Probabilistic Analysis by Optical Computing Methods

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Abstract
The purpose of this article to show the laser coherent photonics methods can be use for classification of medical information. It is shown that the holography methods can be used not only for work with images. Holographic methods can be used for processing of information provided in the universal multi-parametric form. It is shown that along with the usual correlation algorithm enable to realize a number of algorithms of classification: searching for a precedent, Hamming distance measurement, Bayes probability algorithm, deterministic and "correspondence" algorithms. Significantly, that preserves all advantages of holographic method – speed, two-dimension, record-breaking high capacity of memory, flexibility of data processing and representation of result, high radiation resistance in comparison with electronic equipment. For example is presented the result of solving one of the problems of medical diagnostics - a forecast of organism state after mass traumatic lesions.

Keywords: Medical diagnostics; Optical computing; Statistical distributions

Introduction

The high coherent laser radiation is used effectively in different kinds of medical diagnostics such as: optical coherent tomography, research of blood, skin and teeth states, etc. [1]. At the same time in modern medical practice, there is a paradoxical situation: the possibilities of modern physical, instrumental and biochemical analyses, provide a complete description of the state of the patient, but only a doctor of highest qualification or the consultation of specialists able to recognize a large number of parameters and give justified conclusion about diagnosis and optimal treatment strategies. The holographic methods are suitable for diagnosing in the general case of no constraints imposed on the statistical function of system states and permits recognize complicated images. The last years marked the transition from the investigation and construction of simple pattern recognizing devices to the development of complex pattern recognition systems. In holography this process is characterized by the possibility of extension of the range of investigation from the recognition of pattern of natural two-dimensional form [2] to the multi-parameter pattern recognition [3,4]. It is very important and useful for operative analysis and recognition medicine and other complicate situations.

Theory. Holographic Algorithms of Multi-Parametric Analysis

Laser holography is highly suitable for classification of system's states because it offers unique possibilities of parallel processing two-dimensional data arrays, realizing the correlation algorithm in a simple way, handling information rapidly, and providing large memory density and capacity. The certain parameters combination defines a human illness. In this view it is necessary to take into consideration a number of different parameters combination and to compare these multi-parametric results with the previous experience and after that come to a concrete decision.

The complicated state may in general case be described by the position of a point in the m-dimensional space of characters with coordinates $S_1, S_2, \ldots, S_m$, where each particular value of the coordinate corresponds to a definite value of the parameter (character). Objective diagnosis is effected, if the coordinates S_i are chosen so that the space of characters develops the ranges of parameter values that correspond to definite diseases and may be assigned (diagnosed) as such with some probability P_j. The diagnosis can be most reliable if these ranges do not overlap. In practice, one generally has to put up with a partial overlapping of the ranges or approximate them by "wingless" distributions which, though, would lead to an increased number of unstated diagnoses. Accurate separation of diagnostic ranges in the space of characters may be achieved in two ways: by thoroughly selecting the most informative parameters of the system, or by increasing the space dimensionally.

The first approach permits an exquisite solution. However, the search for most informative characters is an insolvable problem not only in the general case but also for most of specific situations. Besides, the weight of characters proves different and depends on the final diagnosis. The second approach would increase the number of parameters, which enlarges redundant information and presents two sorts of difficulties. First, the number of examinations cannot be infinitely large, the more so if the patient is not indifferent to lengthy treatment. Second, increased redundant information would require sorting out a large number of parameters. This, however, is rather difficult to accomplish because the required capacity grows exponentially with the number of parameters.

The simplest diagnostic algorithm is the search for a precedent. This is the only algorithm in which the data being processed virtually equals the storage capacity. Its number of possible states ranges into q^m, where q is the number of possible definite values of a certain parameter, and m is the number of parameters. Such an algorithm does not call for preliminary processing of the initial data, but imposes stringent requirements on the memory capacity. Moreover, the speed in exhaustive search proves the slowest of all. The diagnostic machine turns out system that implements a decision making algorithm. Therefore, machine diagnostics fairly often uses a deterministic method which establishes an explicit connection between definite parameters and diagnostic results, i.e. approximates the actual distribution by an $(m + 1)$ - dimension parallelepiped. If an analyzable system does not fit by one of the parameters it is immediately discarded of those corresponding to a definite diagnosis. But this can result in gross mistakes, particularly where the intelligence weight of individual parameters is not known beforehand.

A more reliable diagnostic procedure seems to be the one using metric methods in a pattern recognition algorithm. These methods employ a certain metric as a diagnostic measure

$$L_j = l_j^{\mu}(\nu)(S,a) = (\sum_{i=1}^{m} \left|S_j - a_{ji}\right|^{\nu})^{\mu/\nu} \qquad (1)$$

where S_i, $i = 1, 2, \ldots, m$ represents the coordinates of the system under study in the space of characters; a_{ji} ($i=1,2,\ldots,m; j=1,2,\ldots,n$) represents the coordinates of a reference point for a diagnosis B_j (a typical state of the system consistent with diagnosis B_j). At $\nu=2$ and $\mu=1$, L_j represents the Euclidean distance; at $\nu=1$ and $\mu= 1$, L_j represents the Hamming distance. In a particular case of recognition in the space of simple characters coded by binary digits, the Hamming distance is the number of bits in the representations of the two points which differ.

Probability algorithms, exploiting statistical distributions, display are the highest flexibility. These relyon the Bayes' theorem, according to which the information contained in a character S_i(or in the system of characters, S) on the condition that disease B_j takes place is equal to the information contained in diagnosis B_j provided that character S_i(or the system of characters, S) takes place. Considering that the total probability

$$P(S) = \sum_{j=1}^{n} P(B_j)P(S|B_j) \quad (2)$$

wearrive at the probability of having the *j*th disease:

$$P(B_j|S) = \frac{P(B_j)P(S|B_j)}{\sum_{j=1}^{n} P(B_j)P(S|B_j)} \quad (3)$$

Here $P(B_j|S)$ is the posterior probability of the *j*th diagnosis on the condition that the system of characters is S; $P(B_j)$ is the prior probability of the jth diagnosis; $P(S|B_j)$ is the probability of possessing the set of characters S disease B_j; and $P(S)$ is the probability that set S is available in the given class of diseases. If the characters are independent, then

$$P(S|B_j) = \prod_{i=1}^{m} P(S_i|B_j) \quad (4)$$

the probabilities $P(B_j|S)$ are readily determinable from available statistics. The required storage capacity will be defined here by the product qm rather than by the power q^m.

In implementing the "probabilistic diagnostics" we assume statistical independence of the parameters. This constraint can be avoided if we take advantage of the "correspondence diagnostics". In essence it is as follows. The initial distribution of $P(B_j|S)$ is approximated by a set of (m+1)-dimensional parallelepiped whose number is determined by the shape of distribution and the desired accuracy in stating the diagnosis probability. With such an approach, the independent classes of diseases result from the value sets of the parameters, which correspond to a definite diagnosis subject to a given probability of the result. The requirements placed on the storage capacity become less stringent than in search for a precedent, but more stringent than for the deterministic method. Besides, the correspondence diagnostics calls for complete initial statistics which has to be processed for store. This is the most general case of classification; it does not limit the independence of parameters and to form the source of the statistical distribution. At the same time it gives information about the probability of possible result diagnoses. This method combines the benefits of deterministic and probabilistic methods, but requires the most serious mathematical processing of initial statistical information.

Experimental Realization and Results

Described the concept of holographic analysis were experimentally tested on real medical task of forecasting the state of the body after mass traumatic lesions. A consideration was given to the immediate prognosis of the states of a heavily injured organism. The first stage involved defining the possible states and their outcomes for the patient. As result we plotted a special medical information chart and compiled the matrices of statistical distributions required to write the data into the holographic store. After data processing we obtained a two-valued medicine card. To improve the reliability and increase the density of information on the hologram we applied prior quantization parameters and reverse paraphrase coding. Reverse paraphrase coding in holography allows increase the signal to noise ratio and eliminates the possibility of false coincident signals. The recording of initial statistical information on the holographic filter and the data input were made with a liquid crystal modulator. To each of the characters there were assigned two cells of the liquid crystal light modulator. Modulation was applied through the dynamic scatter of light by feeding the control potential to the relevant portions of the liquid crystal matrix. Different reference beams were used to record two spatially matched holograms, one for the favorable and the other for the unfavorable outcome of the illness concerned. The decision was made subject to the relative intensity of signals at the output plane.

With the liquid-crystal modulator it takes 0.1s to arrive at a diagnosis. The time can be cut down up to 10^{-5}s by use of a metal-oxide-semiconductor-oxide-metal system or an acousto-optical data input. For acousto-optical data input a special technique of data representation has been worked out. It introduces real-time parameters to the optical system by assigning to each of them a harmonic component from the ultrasonic spectrum. In the simplest case of two-valued parameters, the presence or absence of a particular component in the spectrum will signal one of the two values of the parameter. The input of multivalued and continuously varying parameters is also possible.
The procedure of making out a diagnosis with the aid holography involves the following stages:

1. Data preparation and formalization (see Table 1).

Table 1. MEDICAL FACTS for CASES of DISASTERS
Data of Moscow Sklifosovsky Institute for Emergency Medical Care

№	Title of characters - parameters	Quality of characters	
1.	Type of respirator	Mixed thoraxal +	Diaphragmal
2.	Pathology of respiration rhythm	Yes	No +
3.	Respiration frequency	12 – 24 +	<12 or >24
4.	Emboly of respiration tubes	Yes	No +
5.	Pulse frequency	60 - 120 +	<60 or >120
6.	Filling of Pulse	Full +	Faint
7.	Rhythm of Pulse	Yes +	No
8.	Blood pressure -sist.	140 - 100 +	<100 or >140
9.	Blood pressure -diasist.	40 - 90 +	<40 or >90
10.	Difference between 9.and 8.	30 - 60 +	<30 or >60
11.	Shock	Yes	No +
12.	Skin color	Ordinary +	Pale
13.	State of senses	Safe of part.sense +	Coma
14.	Depth of coma	Live reaction +	Slack reaction
15.	Light reactions of pupil	Yes +	No
16.	Wound of head	Yes	No +
17.	Flow of brain substance	Yes	No +
18.	Wounds of therax	No or not penetr.+	Yes
19.	Fracture of spine column	Yes	No +
20.	Fracturs of other bones	No or sole +	In numbers

2. Initial data coding and recording on optical modulator to form holographic memory.
3. Coding of the examination records on another optical modulator to form data input.
4. Comparison of result patient's examination records with the stored statistical material in holographic memory and final decision making.

A check on a sample of 200 real medicine histories with 20 two levels parameters (one example you can see at the table) revealed that the prognosis provided by the holographic forecast - positive or negative, comparing with real data of Institute for Emergency Medical Care for these statistical data, is over 80%.

Discussion

Holographic methods it is possible and it is expedient to process not only images, but also information provided in universal multiple parameter form. Holography allows realize not only classical correlation algorithm, but also a number of more complicate algorithms of processing. The submitted holographic method are suitable for diagnosing in the general case of no constraints imposed on the statistical function of system's states (correspondence method), and for the cases where the distribution is a histogram(deterministic method) or the parameters of the system are statistically independent (Bayesian method),or the statistical sample has a limited size (metric method).In distinction from the optical methods dealing with the signals and images in the natural form, considered method permits analyze information represented in multi-parametric form, thereby offering a qualitatively new way for optical data processing of medical information**.**

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